Energy Efficiency and Indoor Climate of Apartment Buildings in Estonia

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***Abstract*- During 1960-1990, there was an extensive construction of apartment buildings in Estonia. In 1970s the specific heat consumption of apartment buildings was about 380 kWh/m^2 per year. The 1990s is considered to be the beginning of the renovation of heat substations, heating and ventilation systems, and building envelopes. The renovation of windows in old apartment buildings was accompanied by problems of the indoor climate. The problem of indoor climate of partly renovated old apartment buildings is seriously concerned. With the help of simulation programs energy conservation achievable with renovation and analysing indoor climate has been analysed in apartment buildings. Increase in energy efficiency in buildings with the help of air handling units (AHU) and heat recovery is analyzed. In old apartment buildings one of the possible solutions is the air change arrangement of room heat recovery units and programmable exhaust ventilators in toilets, bathrooms, and kitchens.**

Keywords*- *Heat Consumption; Apartment Buildings; RH Level; CO2 Concentration; Ventilation Systems; Energy Efficiency; Renovation; Simulation of Energy Consumption

I. INTRODUCTION

During1960-1990, there was an extensive construction of apartment buildings in Estonia. Extensive construction activities could be carried out due to the low prices of building materials and fuels. The latter made it possible to use simple solutions in heat supply and ventilation. Extensive use was made of district heating (DH).

Heating systems were connected to DH network by simple jet pump connection mode (Fig. 1).

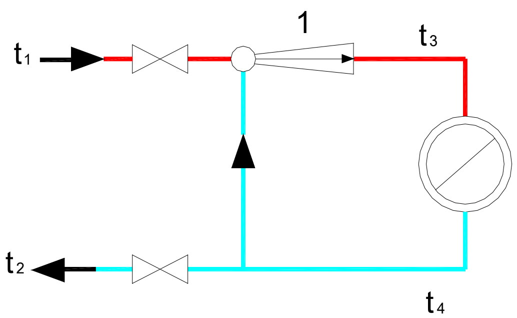

Fig.1 Heat substation that is based on the heating system connected to DH network by jet pump: 1 – jet pump; t_1- flow pipe of DH network; t_2- return pipe of DH network; t_3- flow pipe of heating system; t_4- return pipe of heating system

Predominating in heating the apartment buildings were one-pipe systems (Fig. 2).

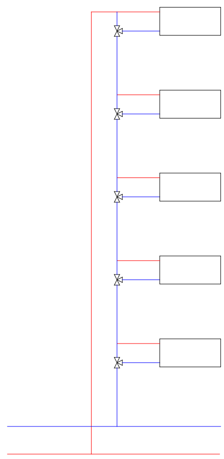

Fig.2 One-pipe heating system with 3-way radiator valves

The advantage of the one-pipe system is that without the up-to-date radiator valves it is possible to secure the stability of the functioning of the heating systems. The latter was the precondition for using a simple and cheap connection mode (the jet pump connection mode, Fig. 1) to connect the heating systems to the district heating network.

Ventilation in apartment buildings was as a rule natural. The Fig. 3 shows two different approaches to natural ventilation: the one on the left for typical 5-storey apartment buildings and the one on the right for typical 9-storey apartment buildings. The natural ventilation operates due to the difference in air density between indoors and outdoors. Additional influence is exercised by the height of ventilation channels and the strength of wind.

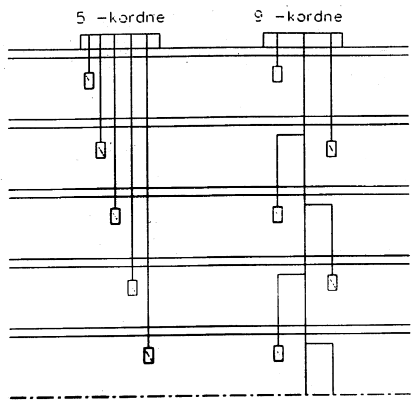

Fig.3 Solutions to natural ventilation for typical apartment buildings

During1960-1990, the U-values of building envelope elements were listed in the following:

- External walls - 1.0…1.3 W/(m^2*K)
- Roof-ceilings – 0.9…1.2 W/(m^2*K)
- Windows – 2.7…2.9 W/(m^2*K).

At the beginning of the 1990s, the first steps were taken in renovating district heating systems. First heat substations were renovated. That made it possible to prevent apartments from overheating at higher outdoor temperatures if the temperature in the flow pipe of DH network is constant (Fig. 4).

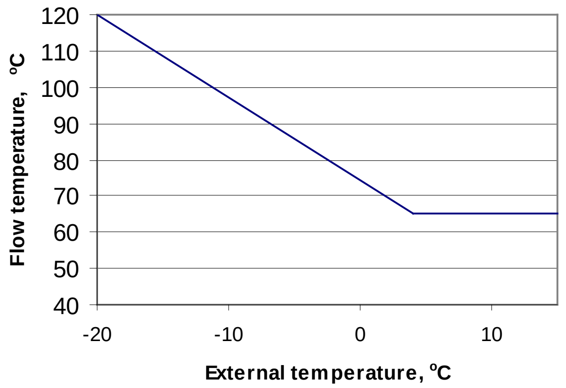

Fig.4 Temperature graph in flow pipes of district heating network

The typical solution of renovated heat substation is presented in Fig. 5.

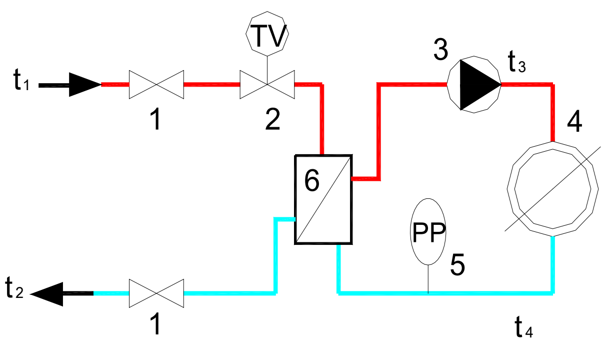

Fig.5 Heat substation for connection of the heating system to DH network by heat exchanger: 1 – valve; 2 – control valve with actuator; 3 – circulation pump; 4 – heating system; 5– expansion vessel; 6 – heat exchanger

At the beginning of the 90s, owing to a rapid rise of fuel prices in Estonia, indoor temperature in apartment buildings was lowered to a certain extent. Inhabitants responded to that by sealing or replacing windows. This, due to a decrease in air change, was accompanied by problems of air quality in apartments.

In the 1970s and the 1980s, the domestic hot water (DHW) consumption in residential buildings was close to 95L per day per person. That was confirmed by the investigations carried out both in Estonia and in the Soviet Union [1, 2].

In that period the specific heat consumption of apartment buildings made up to 380 kWh/m2 per year (i.e. per heated area of the apartments), including the DHW heating which was up to 140 kWh/m^2 per year and losses of DHW network in buildings.

In 1990s, there was an extensive renovation of DHW systems: the piping was renovated, the circulation system was balanced and made to work, water meters were installed in apartments, and the inhabitants had to pay for the water they consumed. Water outlets in apartments were also renovated [3]. At the same time, there was a constant rise in the prices of water and heat. The impact of these measures is reflected in a decrease in DHW consumption (Fig. 6).

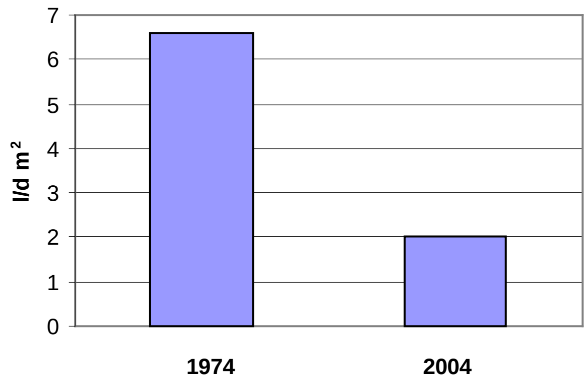

Fig.6 DHW consumption in apartment buildings in 1974 and 2004

Fig. 6 characterizes the DHW consumption in different periods of time: 6.6 L/per m2 per day in 1974 and 2 L/per m2 per day in 2004.

Average energy consumption on water heating in the year 2009 was about 100 kWh/ m2 and in the year 2004 90 kWh/m2 less than in 80s (Fig. 7). The same time saw the renovation of windows and other envelope elements, and heating systems. The influence of the renovation and conservation measures on energy consumption can be seen in Fig. 7.

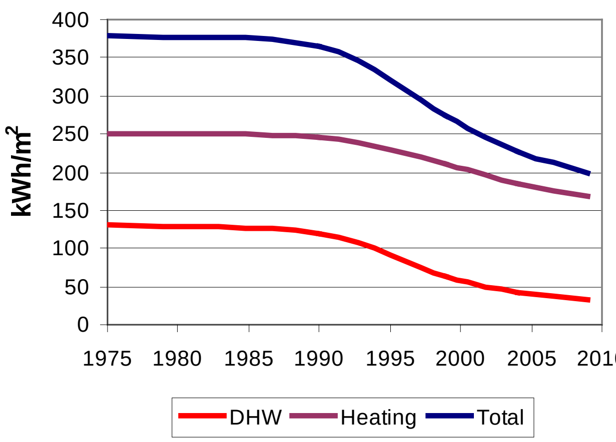

Fig.7 Approximated heat consumption on DHW, heating and total for years 1975-2009 (per gross area of apartments)

Problems of energy conservation and indoor climate in residential buildings and the importance of them have been dealt with by many authors such as Ken-ichi Kimura [4], Walker [5], Koiv [6], [7], Mikola [8], Tali [9], Energy [10], Energy-Efficient [12], Stavova [13]. The energy efficiency of apartment buildings has been investigated by many researchers [11, 14, 15, and 16].

II. PROBLEMS

A. Indoor Climate Investigation in Apartment Buildings

This problem of indoor climates of old and partly renovated apartment buildings is seriously concerned. In Fig. 8, we can see that in the partly renovated apartment buildings (new hermetic windows, renovated envelope and heating system, but old natural ventilation system) relative humidity (RH) arise up to 80% in wintertime. The carbon dioxide concentration level in the bedrooms of an old apartment building at night is given in Fig. 9.

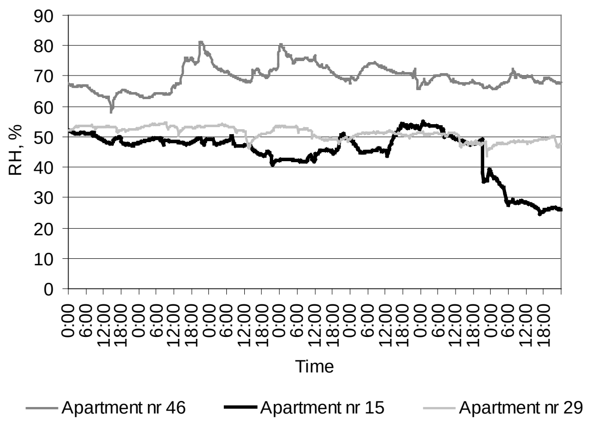

Fig.8 Relative humidity level in the bedrooms of partly renovated 60-apartment building in the wintertime (2009) with external temperature being from -5 to -8°C

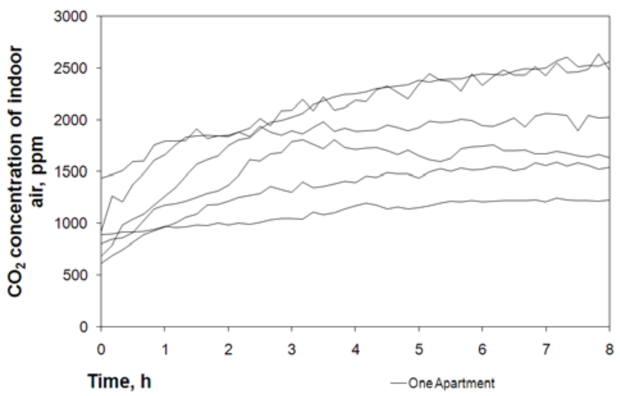

Fig.9 The carbon dioxide concentration level in the bedrooms of an old apartment building at night

The results of measuring the CO2 concentration in old apartment buildings with natural ventilation showed a high level, by the waking up time the CO2 level had been up to 2500 ppm.

By now a large number of old windows have been exchanged in old apartment buildings for modern ones which are essentially more hermetic, for instance, in Tallinn about two thirds have been exchanged. This has resulted in the heat resistance of the windows increasing by about one third. At the same time, the installation of new windows made the air change in apartment buildings with natural ventilation to decrease by about three times, resulting in serious disorders in the indoor climate.

In apartment buildings where the envelope and the heating system have been renovated but the ventilation not, one can see that the permitted level of carbon dioxide has been surpassed up to about three times of that level and the relative humidity about two times.

An essential role in the CO2 concentration in bedrooms is played by the position of the door: if the door is closed, the CO2 level is high (Fig. 10).

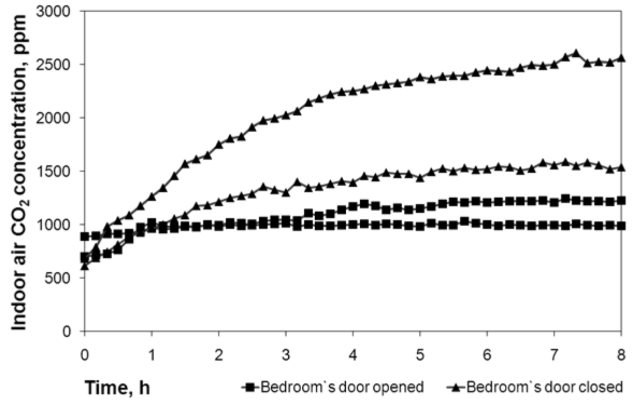

Fig.10 Carbon dioxide concentration level in two bedrooms in case the door of the room is opened or closed

Figs. 11 and 12 present the RH and the CO2 cumulative graphs in un-renovated apartment buildings with natural ventilation.

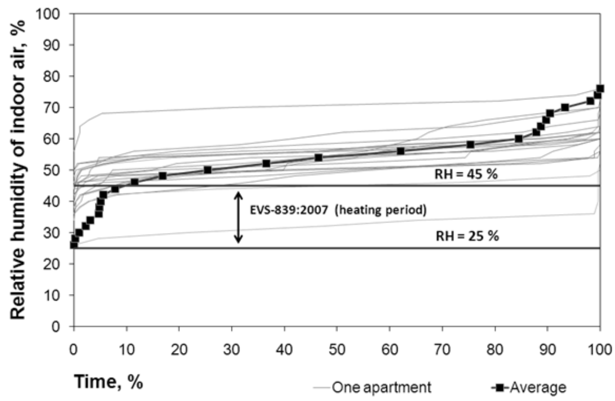

Fig.11 Cumulative graph of relative humidity level in bedrooms (in 20 different apartments) of 9-storey apartment building in winter period

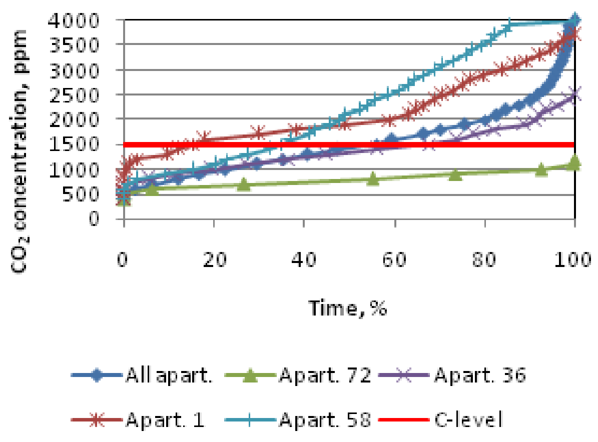

Fig.12 Cumulative graph of carbon dioxide level in bedrooms of 9-storey apartment building

As it can be seen, extensive indoor climate investigation in a 9-storey apartment building showed a generally high carbon dioxide level in bedrooms. External temperature increased from -3 to +9°C [18].

Air change in bedroom with natural ventilation can be determined by Equation (1) [14].

$$\frac{L}{V}\cdot\tau=-\ln\frac{\frac{m}{L}+C_v-C}{\frac{m}{L}+C_v-C_o} \qquad (1)$$

where
m - carbon dioxide generation in room,
L - air change in room,
V - volume of room or design volume,
Cv - carbon dioxide concentration in external air (in supply air),
C - carbon dioxide concentration in room air (in exhaust air),
Co- carbon dioxide concentration in the air of the room at the beginning of the human activity,
τ - time.

Air flow rates determined by the Equation (1) give satisfactory results.

Measuring results of air flow rates in bedrooms of different apartments is given in Table Ⅰ and Ⅱ.

TABLE I BEDROOMS AIR FLOW RATE (AUTUMN)

Code	Floor	Number of People	Windows	Air Change Rate [L/s]
1001	7	2	New	4,17
1002	2	2	Old	1,24
1003	1	1	New	1,16
1004	9	2	New	2,50
1005	5	2	New	0,71
1006	9	1	Old	6,40
1007	9	1	New	1,99
1008	6	2	New	0,67
1011	5	1	New	1,72
1012	6	1	New	3,0

TABLE II BEDROOMS AIR FLOW RATE (WINTER)

Code	Floor	Number of People	Windows	Air Change Rate [L/s]
1001	7	2	New	3,07
1002	2	2	Old	2,14
1003	1	1	New	1,34
1004	9	2	New	2,95
1005	5	2	New	0,74
1006	9	1	Old	6,99
1007	9	1	New	2,67
1008	6	2	New	1,08
1009	5	2	Old	1,57
1010	6	1	New	3,60

Exhaust air flow rates of the kitchen and WC/bathroom for the winter period is presented in Table III.

TABLE III EXHAUST AIR FLOW RATES OF KITCHEN AND WC/ BATHROOM FOR THE WINTER PERIOD

Code	Floor	Number of People	Windows	Air Change Rate [L/s]
1001	7	3	New	14,0
1002	2	3	Old	2,2
1003	1	3	New	4,3
1004	9	3	New	7,8
1014	9	2	New	7,5
1006	9	3	Old	11,0
1007	9	2	New	8,5
1008	6	2	New	5,0
1011	9	3	New	1,5
1015	9	3	New	39,8
1009	5	3	Old	12,8
1016	9	2	New	2,3
1017	6	3	New	6,8
1013	8	2	Old	4,5

In Fig. 13, Air flow rates in bedrooms during winter and autumn period are presented.

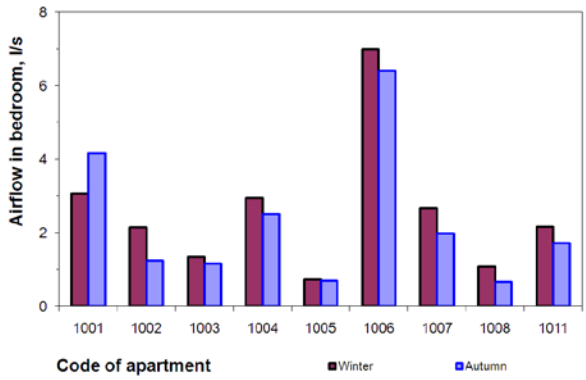

Fig.13 Air flow rates in bedrooms during winter and autumn period

We can see great fluctuation of air change in apartments with natural ventilation. In these apartments mold is quite frequent.

B. *Indoor Climate Simulation in Un-renovated Apartment Buildings*

The relative humidity, CO2, and air change modeling results for the period of year in a model apartment (two rooms apartment) are presented in Figs. 14, 15 and 16. Simulation software IDA ICE was used. The simulation results showed a very high indoor air RH variation (from 10 to 80%) in bedrooms of the standard apartments.

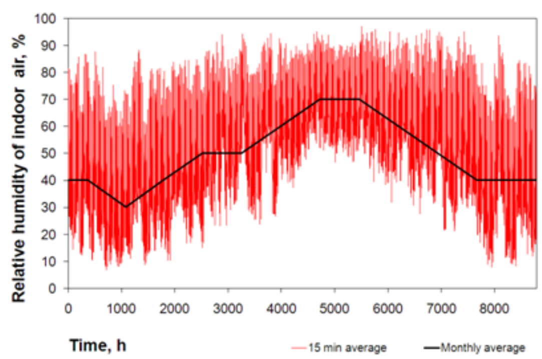

Fig.14 Indoor relative humidity in bedroom (door closed) for period of year

Fig. 14 characterizes the simulation results of the CO2 concentration in in bedrooms of the standard apartments for

period of year. We can see great fluctuation of CO2 level in different time of year.

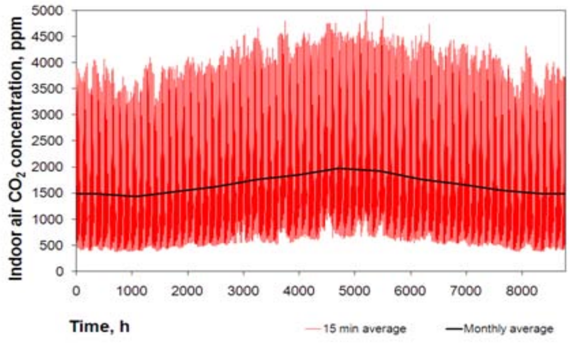

Fig.15 CO2 level in bedroom (door closed) for period of year

Fig. 15 shows that the standard apartment has a large air change fluctuations. If in the spring, autumn and winter period an average air change rate is 7-9 l/s, then in summer it is 1.5 times lower with air change rate fluctuating between 0 and 11 L/s.

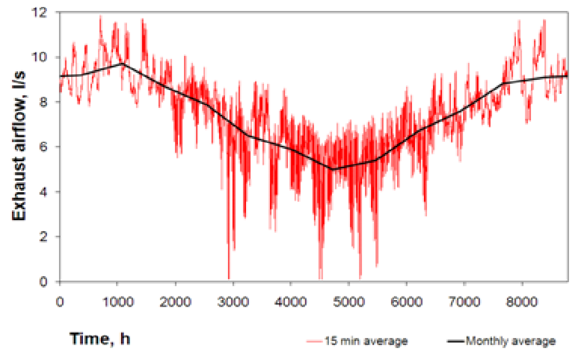

Fig.16 Air change rates in bedroom (door closed) for period of year

III. SOLUTION OF THE PROBLEM

A. *Renovation of the Envelope Elements and Heating-Ventilation Systems*

Envelope elements of old apartment buildings have been more and more actively renovated. Unfortunately, quite often, only part of the envelope elements have been renovated, while the heating systems have not been equipped with a control valves on the heating coils, so the conservation of energy has remained much smaller than expected. In case the envelopes and the heating systems have been completely renovated, energy conservation up to 55% has been obtained. As the ventilation systems have remained unrenovated, a remarkable part of the energy conservation has been achieved at the expense of a decrease in air change that is at the expense of the deterioration of the indoor climate.

New apartment buildings predominantly use mechanical exhaust ventilation, guarantees good indoor climate in apartments. Due to the absence of heat recovery units, the costs of heating the air in such buildings are equal or even surpass those of the heat losses of the envelope. One of the solutions to the problem is recoverying heat of exhaust air by heat pump.

In old apartment buildings, one of the possible solutions is the air change arrangement by room heat recovery units and programmable exhaust ventilators in toilets, bathrooms, and kitchens.

Successful renovating the ventilation systems in old apartment buildings is somewhat complicated, because the renovated system should:

- Be energy efficient;
- satisfy the requirements of the indoor climate;
- have a moderate cost;
- and satisfy the basic wishes of the inhabitants.

Increasing the efficiency of natural ventilation in old apartment buildings (with renovated windows) is usually practiced with the help of exhaust air valves in the external wall.

With individual energy meters on heating coils, inhabitants trying to economize on heat energy and pay less have started to close the fresh air valves. So the pre-renovation situation is almost restored.

Renovated ventilation should be energy efficient, which means it should have heat recovery; but at the same time it should be easily regulated to satisfy the wishes of different inhabitants. Such requirements are best met by the

- supply-exhaust apartment AHU (air handling unit) or
- supply-exhaust room AHU and with controlled exhaust ventilation from the WC/bathroom and kitchen.

Use of the first system is complicated in the existing apartments due to the mounting of air channels in apartments and high cost.

B. *Energy Consumption Analysis by Simulation*

Energy consumption simulations in the apartment building are carried out with the software IDA ICE. The heated area of the studied building is 2790 square meters. The number of apartments is 60. Energy consumption simulations carried out with software IDA ICE show good possibilities of diminishing the energy consumption of the existing old buildings.

The U-values of the building envelope before and after renovation are given in Table Ⅳ. The data of air change before and after renovation for different packets are given in Table Ⅴ.

TABLE IV BUILDING ENVELOPE ELEMENTS U-VALUES BEFORE AND AFTER RENOVATION

Envelope Element	Before Renovation [W/(M2·K)]	After Renovation [W/(M2·K)]
External Wall	1.0	0.18
Roof	0.9	0.12
Cap	2.4	0.28
Window	Old 2.9; New 1.6	1.1

TABLE V DATA ABOUT VENTILATION IN THE APARTMENT BUILDING

Packet	Air Change (Ventilation) [L/S]	Air Change (Infiltration) [L/S]	Temperature Ratio for Heat Recovery Unit
O	505	358	
A	1010	179	
B	489*,**	179	0,6
C	2700**	179	0,6
D	2700**	179	0,8

*Exhaust air flow rate from WC/bathroom and kitchen 25 L/s per apartment during one hour per day

**From 9.00 to 17.00 air flow rate is an half of nominal.

The results of simulation are given in Table Ⅵ and in Fig. 17.

TABLE VI ENERGY CONSUMPTION BY SIMULATION FOR DIFFERENT PACKETS

Packet	Space Heating* [kwh/M2]	Electricity for Fans [kwh/M2]	Electricity for Air Heater [kwh/M2]	Energy Consumption [kwh/M2]
0	189,8	0	0	189,8
A	114,5	0	0	114,5
B	85,5	2,8	0	88,3
C	85,5	11,5	30,7	127.7
D	85,5	11,5	18,1	115,1

* DHW consumption 33 kWh/m2 included

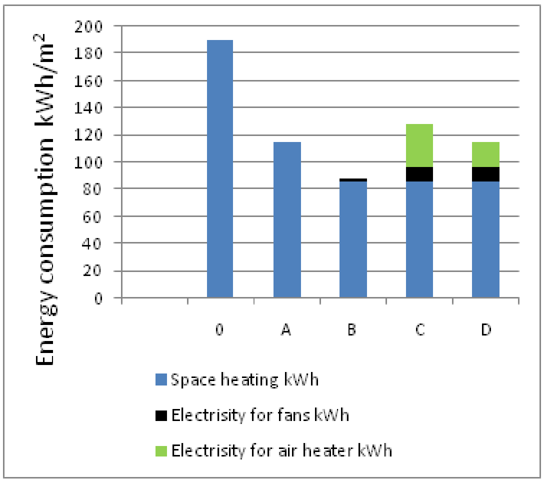

Fig.17 The results of simulation for different packets

Table Ⅵ shows that by renovating the envelope elements and the heating system of the old apartment building as well as by supplying the ventilation system with a heat recovery unit, it is possible to save energy consumption up to 55%.

It can be seen that, in the case of the ventilation Packet A, a large part of the energy saved by the insulating of the envelope is spent on the necessary air change (the primitive solution of the ventilation without heat recovery). The Packets B, C and D are all acceptable from the energetic point of view as well as from that of the indoor climate. The best indoor climate is achieved by Packets C and D.

Energy consumption simulations carried out show the possibilities of considerable diminishing of the energy consumption of the existing buildings.

IV. CONCLUSIONS

Within twenty-five years from 1975 to 2000, energy consumption in apartment buildings has decreased by approximately 130 kWh per m2. The majority of that is made up of more than threefold decrease in the DHW consumption, but also the renovation of heat substations and the lowering of the internal temperature in apartments.

Investigations carried out show that old apartment buildings with natural ventilation have serious problems with indoor climate. Problems are grater in apartments with renovated windows. Investigations have shown that the carbon dioxide level in bedrooms amounts to 4000 ppm and the relative humidity up to 80%. Because of high thermal conductivity of the envelope elements we can often observe the existence of mould.

The simulations carried out show that the renovation of the envelope and the heating system together with the use of flexible AHU with heat recovery makes it possible to considerably save energy. To normalize air change in 5-story old apartment buildings, it is convenient to use room AHU with flexibly functioning exhaust air ventilators in the WC/bathroom and kitchen.

It can be said that the renovations of the envelope elements and the heating and ventilation systems of old apartment buildings make it possible to save energy consumption up to 55% and to improve the quality of indoor air. Renovation of ventilation system and a good maintenance of it make it possible to solve air quality problems and at the same time to increase energy efficiency in residential buildings.

V. ACKNOWLEDGEMENT

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